Supplementary Information for

Recent Southwestern U.S. drought influenced by anthropogenic aerosols and tropical ocean warming

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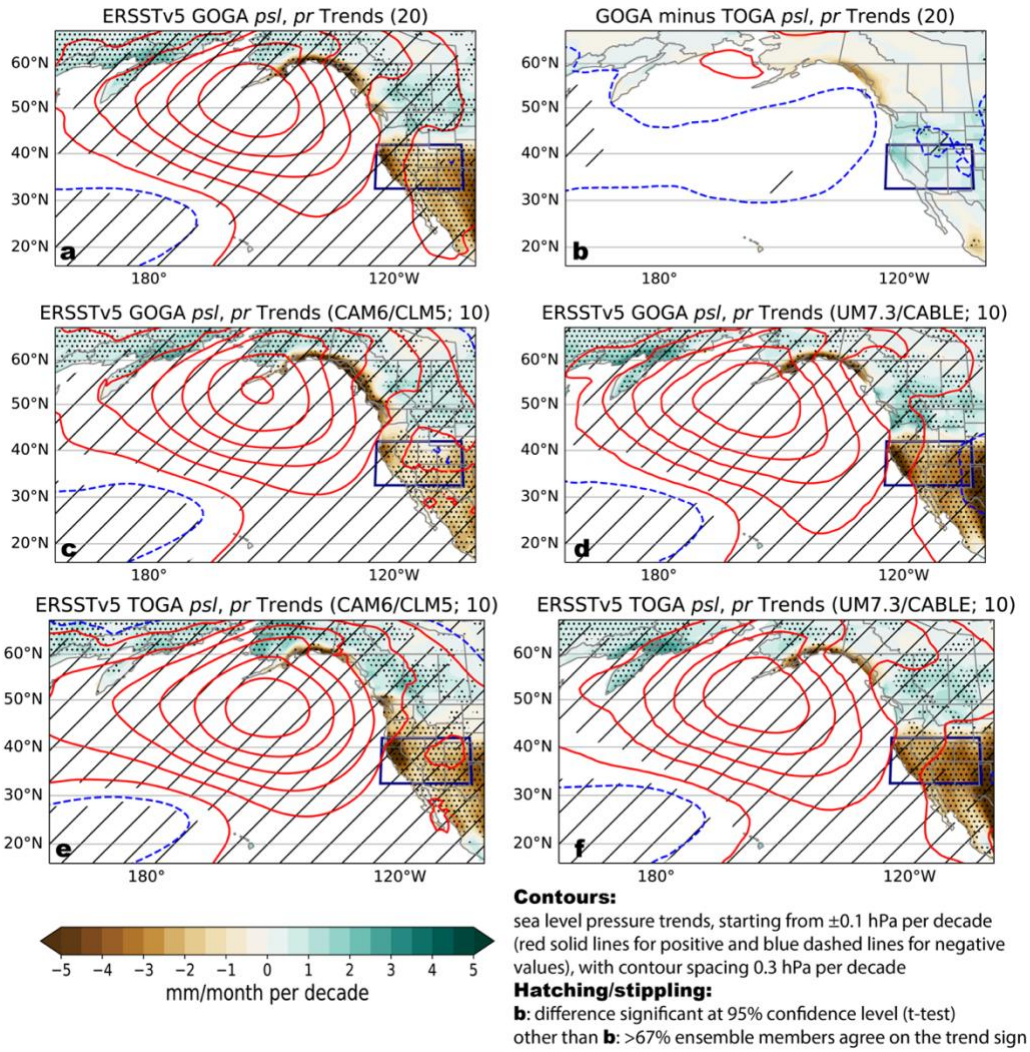

Figure. S1. DJFMAM sea level pressure (psl) and precipitation (pr) trends over 1980-2014. *Trends from* ***a****, global ocean global atmosphere (GOGA; i.e., standard AMIP experiment) simulation (20; including both CAM6/CLM5 and UM7.3/CABLE),* ***b****, the difference between GOGA (20) and TOGA (20),* ***c****, GOGA from CAM6/CLM5 (10),* ***d****, GOGA from UM7.3/CABLE (10),* ***e****, GOGA from CAM6/CLM5 (10),* ***f****, TOGA from UM7.3/CABLE (10). The Hatching/Stippling in (****a****,* ***c****,* ***d****,* ***e****,* ***f****) indicates 67% of the ensemble members agree with the sign of ensemble mean trend. The Hatching/Stippling in* ***b*** *indicates the difference between GOGA and TOGA is significant at 95% confidence level (t-test).*

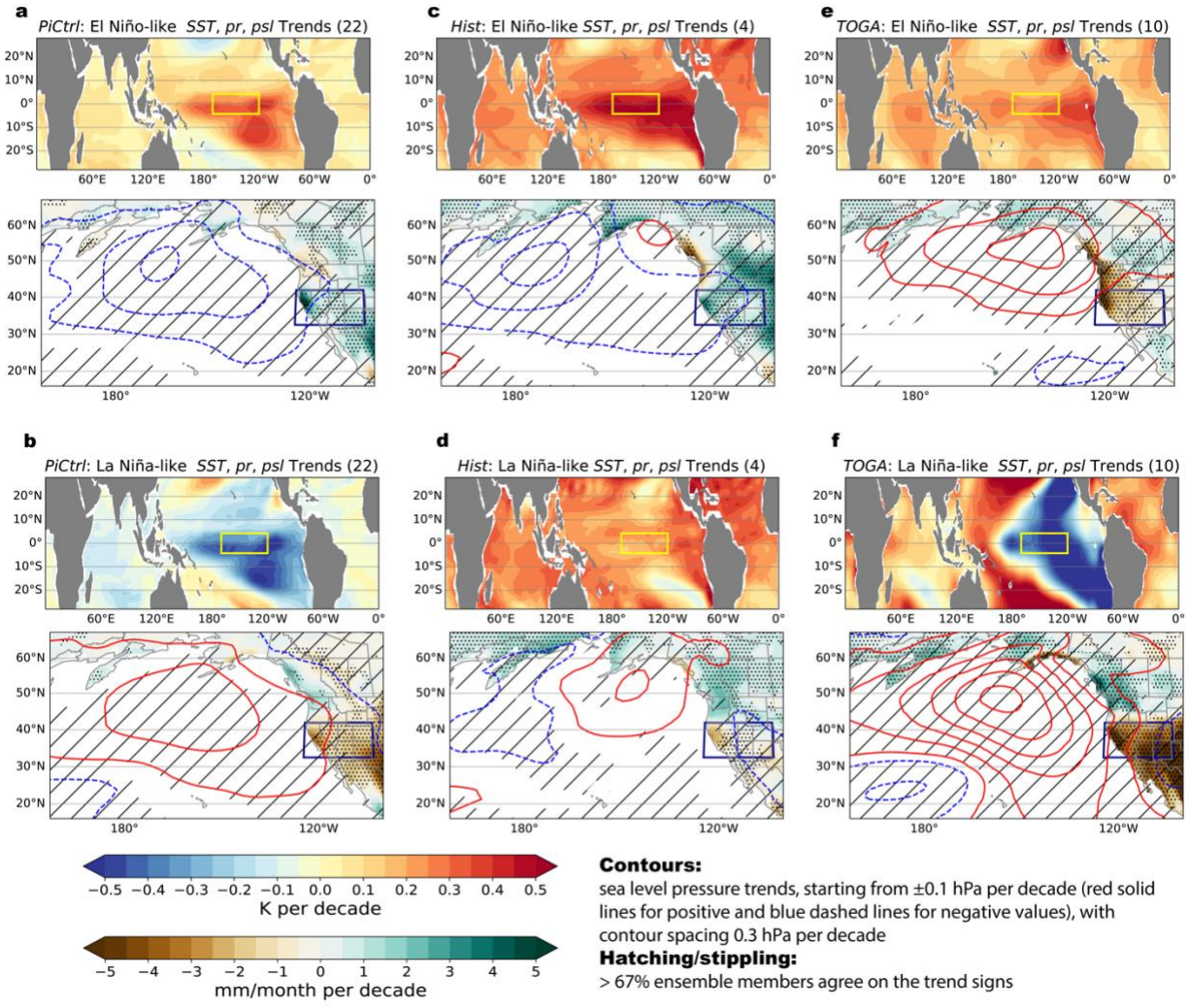

Figure S2. Same as Fig. 2c-2h but from ACCESS-ESM1.5.

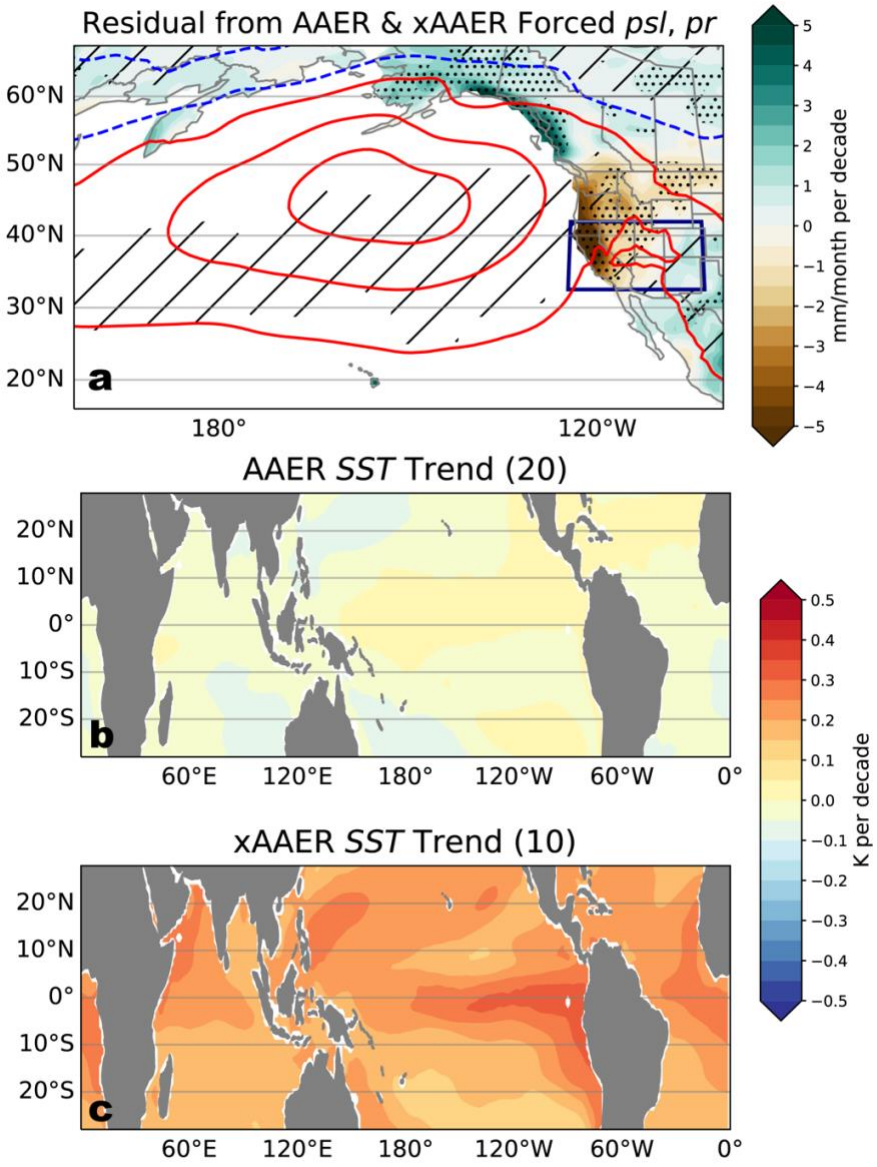

Figure S3. The residual DJFMAM trends in fully coupled large ensemble and single forcing simulations and the sea surface temperature trends in single forcing simulations. a*, The residual trends of psl and pr from the Anthropogenic Aerosols (AAER) and everything-but-anthropogenic aerosols (xAAER) forcing simulations. The residual trends are calculated as the difference between the all forcing large ensemble (Fig. 1g) and the sum of the AAER (Fig. 3e) and xAAER (Fig. 3f). The tropical SST trend from* ***b****, AAER, and* ***c****, xAAER simulations.*

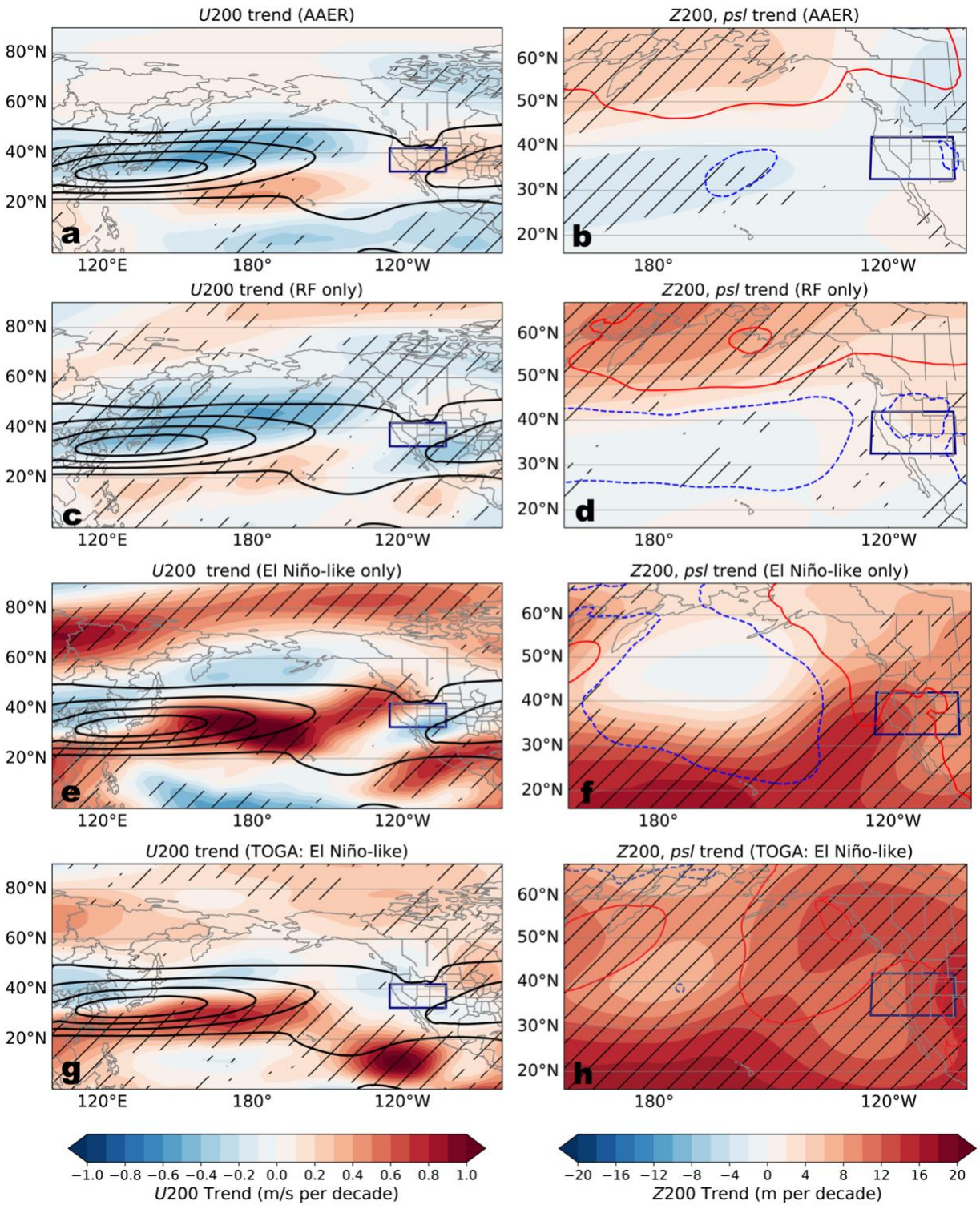

Figure S4. DJFMAM trends of 200 hPa zonal wind (U200), 200 hPa geopotential height (Z200), and sea level pressure for 1980-2014. *(**a, b**) anthropogenic aerosol*

*(AAER) simulation, (**c, d**) radiative forcing only (RF only) simulation, (**e, f**) El Niño-like only simulation, and (**g, h**) TOGA: El Niño-like simulation. Black contours in (**a, c, e, g**) are the DJFMAM climatological U200 from the F2000climo control run, starting from 20 m/s with a contour spacing 10 m/s, and hatching indicates 67% of the ensemble members agree on the change in U200. Red/Blue contours in (**b, d, f, h**) are sea level pressure trend shown in the Main text, and hatching indicates 67% of the ensemble members agree on the change in Z200.*

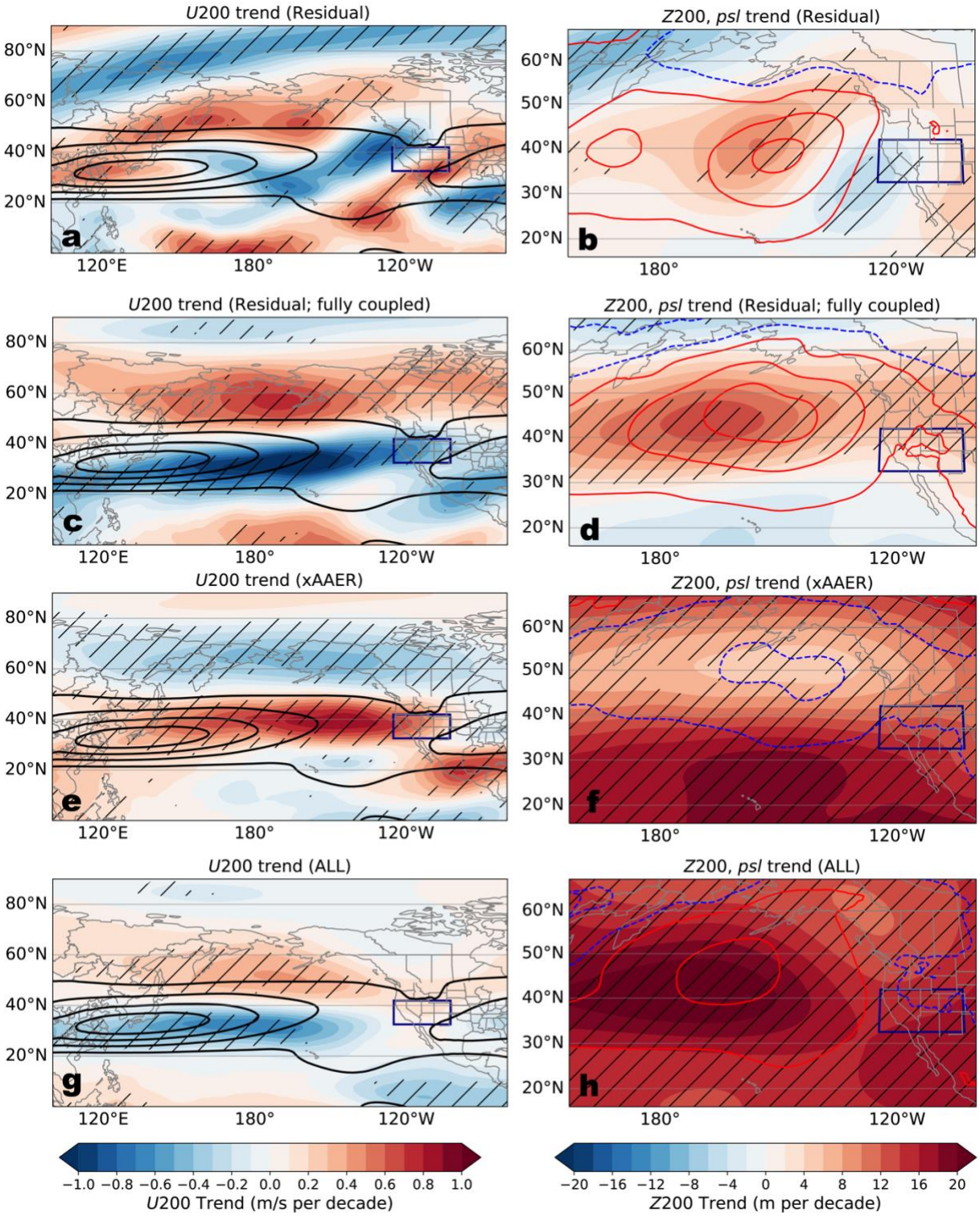

Figure S5. Continuted DJFMAM trends of 200 hPa zonal wind (U200), 200 hPa

geopotential height (Z200), and sea level pressure for 1980-2014. *(**a, b**) residual from El Niño-like only and RF only, (**c, d**) residual from AAER and xAAER, (**e, f**) xAAER, and (**g, h**) ALL. Black contours in (**a, c, e, g**) are the DJFMAM climatological U200 from the F2000climo control run, starting from 20 m/s with a contour spacing 10 m/s, and hatching indicates 67% of the ensemble members agree on the change in U200. Red/Blue contours in (**b, d, f, h**) are sea level pressure trend shown in the Main text, and hatching indicates 67% of the ensemble members agree on the change in Z200.*

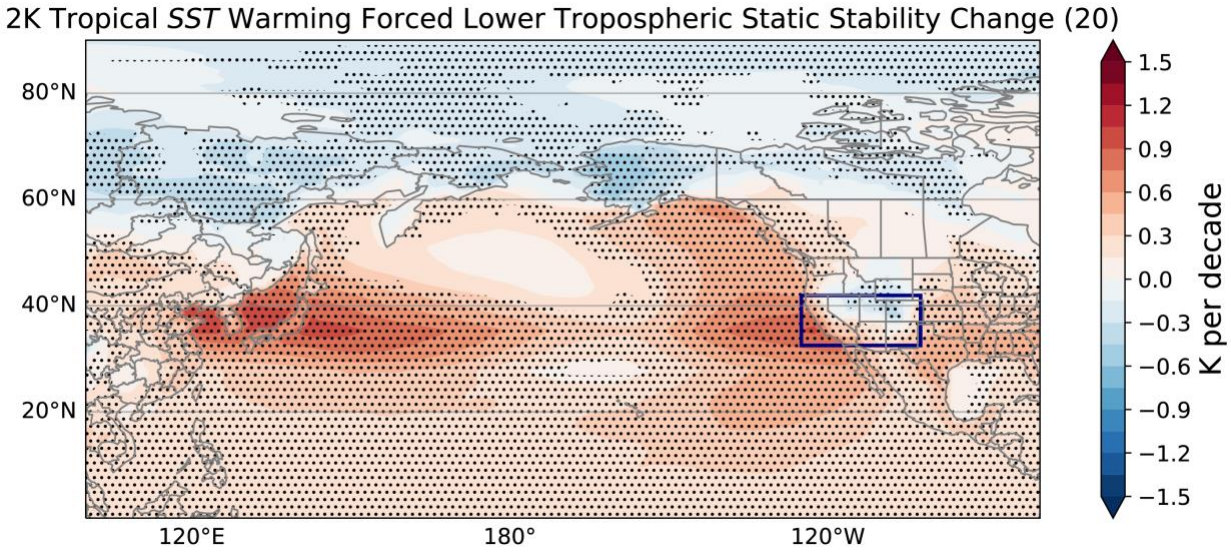

Figure S6. DJFMAM lower tropospheric static stability change under 2K uniform tropical warming. *The lower tropospheric static stability is defined as the difference of the potential temperatures at 700hPa and at the surface. Stippling indicates 67% of the ensemble members agree with the sign of ensemble mean change.*

Table S1. CMIP6 models used in this study. *"v" indicates the simulations from a specific model is included for this study; otherwise, the box is left blank. We used all the r1i1p1f1 from models that provided historical and four SSP scenarios (ssp126, ssp245, ssp370, and ssp585) experiments for all the variables used in this study (tos, tas, pr, psl, mrsos). We also include the last 300 years from the piControl simulation from all the models except FGOALS-f3-L and KACE-1-0-G, as their piControl simulation does not have mrsos output on the CMIP6 archive.*

Model name	PiControl	Historical	SSP126	SSP245	SSP370	SSP585
ACCESS-CM2	v	v	v	v	v	v
ACCESS-ESM1.5	v	v	v	v	v	v
BCC-CSM2-MR	v	v	v	v	v	v
CESM2-WACCM	v	v	v	v	v	v
CESM2	v	v	v	v	v	v
CMCC-CM2-SR5	v	v	v	v	v	v
CMCC-ESM2	v	v	v	v	v	v
CanESM5	v	v	v	v	v	v
EC-Earth3	v	v	v	v	v	v
FGOALS-f3-L		v	v	v	v	v
FGOALS-g3	v	v	v	v	v	v
GFDL-ESM4	v	v	v	v	v	v
IPSL-CM6A-LR	v	v	v	v	v	v
KACE-1-0-G		v	v	v	v	v
MIROC6	v	v	v	v	v	v
MPI-ESM1-2-LR	v	v	v	v	v	v
MRI-ESM2-0	v	v	v	v	v	v

Table S2. Atmospheric Generation Circulation Model (AGCM) used in this study.

Simulation Name	Models	Simulation Summary	Ensemble members
GOGA: ERSSTv5	CAM6/CLM5, UM7.3/CABLE	• AMIP type experiment, capturing the signal of historical changes due to observed *global* SST and radiative forcings • Time evolving forcings: ○ 1978-2014 ERSSTv5 monthly SST prescribed globally ○ 1978-2014 full historical radiative forcings	10 (CAM6/CLM5), 10 (UM7.3/CABLE)
TOGA: ERSSTv5	CAM6/CLM5, UM7.3/CABLE	• AMIP type experiment, capturing the signal of historical changes due to observed *tropical* SST and radiative forcings • Time evolving forcings: ○ 1978-2014 ERSSTv5 monthly SST prescribed in the tropic (28S-28N) ○ 1978-2014 full historical radiative forcings	10 (CAM6/CLM5), 10 (UM7.3/CABLE)
TOGA: El Niño-like	CAM6/CLM5, UM7.3/CABLE	• AMIP type experiment, capturing the signal of historical changes due to tropical SST (generated from LIM with El Niño-like trend) and radiative forcings • Time evolving forcings: ○ 1978-2014 monthly LIM-generated SST with El Niño-like trend prescribed in the tropic (28S-28N) ○ 1978-2014 full historical radiative forcings	10 (CAM6/CLM5), 10 (UM7.3/CABLE)
TOGA: La Niña-like	CAM6/CLM5, UM7.3/CABLE	• AMIP type experiment, capturing the signal of historical changes due to tropical SST (generated	10 (CAM6/CLM5), 10 (UM7.3/CABLE)

		from LIM with La Niña-like trend) and radiative forcings
		• Time evolving forcings:
		  ○ 1978-2014 monthly LIM-generated SST with La Niña-like trend prescribed in the tropic (28S-28N)
		  ○ 1978-2014 full historical radiative forcings	

RF only	CAM6/CLM5	• AMIP type experiment, capturing the signal of historical changes due to radiative forcings when SST held fixed • Time evolving forcings: ○ 1978-2014 full historical radiative forcings	10

F2000climo	CAM6/CLM5	• AMIP type anomaly experiment control run, capturing climate under the year 2000 forcings
		• Forcings:
		  ○ Climatological 1880-2019 ERSSTv5 monthly SST and HadISST sea ice
		  ○ Radiative forcings representing year 2000 climate
			23 simulated years

F2000climo-TOGA: El Niño-like	CAM6/CLM5	• AMIP type anomaly experiment experimental run with tropical El Niño-like trend, capturing climate under the year 2000 forcings and tropical El Niño-like trend Forcings are identical to F2000climo but with SST trends from *TOGA: El Niño-like* as anomalies for SST within 28N/S	23 simulated years
F2000climo-trop2K	CAM6/CLM5	• AMIP type anomaly experiment experimental run with tropical 2K warming trend, capturing climate under the year	23 simulated years

		2000 forcings and tropical 2K warming trend • Forcings are identical to F2000climo but with a 2K warming anomaly for SST within 28N/S	

Note

- The first two years in AMIP type transient runs and AMIP type anomaly experiments are considered spinup and are disregarded.
- El Niño-like only in the main text is the difference between F2000climo-TOGA El Niño-like and F2000climo.
- 2K only in the main text is the difference between F2000climo-trop2K and F2000climo.

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